are used to provide combustion air. Overfire air and reinjection fans for stokers and primary air fans for pulverizers may also be required. Induced draft fans are used to pull the flue gas from the furnance through the boiler bank and any ductwork, economizer, air heater, or dust collector provided.

e. Controls and Instrumentation. Since operator safety and protection of the boiler are of great importance, boiler feedwater controls and burner safety controls are required to guard against failures due to low boiler water or explosion. Combustion controls regulate the fuel and air flow to maintain efficient combustion. The high price of boiler fuel which justifies improved combustion controls also justifies the use of recorders and meters to monitor combustion and ensure optimum plant operation.

f. Pollution Control Equipment. The combustion of fuel may generate a variety of pollutants in excess of limits set by regulatory agencies. The major pollutant emissions of present concern are particulate, oxides of sulfur (SOx), and oxides of nitrogen (NOx). The use of a fuel lower in ash or surfur content and modifications to the combustion process can be effective in reducing these emissions. If these fuels are too expensive or combustion modifications only partially effective, pollution control systems can also be used to bring emissions within acceptabe limits. Typical pollution control systems are mechanical collectors, fabric filters, electrostatic precipitators, wet scrubbers, and tall stacks.

g. Water Treatment Systems. Proper water treatment prevents scale formation on the internal surfaces of the boiler and reduces boiler and distribution system corrosion. Water treatment often involves a combination of external and internal techniques. External water treatment includes removal of suspended matter with clarifiers and filters; reduction of water hardness with lime or zeolite softeners or demineralizers; and reduction of corrosive gases with deaerators. Internal water treatment involves injection of chemicals directly into the boiler to control any impurities remaining after external treatment chemicals include caustic to aid precipitation, phosphate for hardness removal, and dispersants to aid precipitate removal by blowdown. Specific equipment is also required for boiler blowdown systems and testing purposes to monitor and maintain a functional water treatment system.

h. Water Supply Equipment. Feedwater is supplied to steam boilers by means of centrifugal or reciprocating pumps. Centrifugal pumps are also typically used to circulate water through high temperature water boilers and their associated distribution systems.

i. Distribution Systems. The energy produced in the central boiler plant, whether in the form of steam or hot water, must be transferred to other buildings through a distribution system. The distribution system also returns unused energy in the form of hot water or condensate to the central plant for recycle. The distribution system consists of insulated, weatherproof pipelines, valve pumps, regulators, and heat exchangers. Steam systems also include traps and condensate handling of equipment.

j. Miscellaneous. Each central boiler plant has its own unique set of maintenance tools and spare parts inventory. Also unique to a given plant is its electric power distribution system, air compressors, and emergency generator sets.

SECTION II. ELEMENTARY COMBUSTION PRINCIPLES

1-4. FOSSIL FUELS

Fossil fuels are derived from the remains of plant and animal organisms. These organisms used carbon dioxide (CO_2), minerals, water, and energy from sunlight to grow. Over millions of years this material accumulated and the original carbohydrates and other organic materials were buried and converted to the hydrocarbon or fossil fuels we use today. These fossil fuels are found in solid, liquid, and gaseous form.

a. Coal. Coal is a solid fossil fuel. Coal's characteristics are directly affected by its age, since the plant matter from which it was formed first changes to peat, then with sufficient heat, pressure, and time to brown coal or lignite, subbituminous coal, bituminous coal, and finally anthracite — the oldest of coals. If anthracite were submitted to additional pressure and heat, graphite and eventually diamonds would be produced. Considering the cost of coal today, it is worth thinking of coal as young diamonds.

(1) In the United States, lignite is found primarily in North Dakota, Montana, and Texas, with proven reserves of 447 billion tons. Subbituminous coal is found in Montana, Wyoming, Washington, and Alaska with proven reserves of 437 billion tons. Bituminous coal is found in at least twent-eight states with proven reserves of over 800 billion tons. Anthracite is found in Pennsylvania, Alaska, Arkansas, and Virginia with proven reserves of 25 billion tons. Because of its widespread availability and subsequently lower transportation costs, bituminous coal is most frequently used. Table 1-1 outlines the classification of coals as given by ASTM D 388. This standard establishes ranges for fixed carbon, volatile matter, and heating value for each class and group of coals.

(2) Coal is a highly complex fuel. Most of its heating value exists in the form of carbon, which is present

Table 1-1. Classification of Coal

Class	Group	Fixed Carbon Limits Percent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, Percent (Dry, Mineral-Matter-Free Basis)		Calorific Value Limits Btu Per Pound (Moist, Mineral-Matter-Free Basis)	
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than
I. Anthracitic	1. Meta-anthracite	98	--	--	2	--	--
	2. Anthracite	92	98	2	8	--	--
	3. Semianthracite	86	92	8	14	--	--
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	--	--
	2. Medium volatile bituminous coal	69	78	22	31	--	--
	3. High volatile A bituminous coal	--	69	31	--	14 000	--
	4. High volatile B bituminous coal	--	--	--	--	13 000	14 000
	5. High volatile C bituminous coal	--	--	--	--	11 500	13 000
						10 500	11 500
III Subbituminous	1. Subbituminous A coal	--	--	--	--	10 500	11 500
	2. Subbituminous B coal	--	--	--	--	9 500	10 500
	3. Subbituminous C coal	--	--	--	--	8 300	9 500
IV Lignitic	1. Lignite A	--	--	--	--	6 300	8 300
	2. Lignite B	--	--	--	--	--	6 300

in two forms, fixed carbon and volatile matter. Volatile matter consists of easily gasified carbohydrates and hydrocarbons. The relationship between these two forms of carbon is one of primary factors in determining how readily a particular coal burns. Coal analyses may be provided in one of two forms, proximate and ultimate. A proximate analysis includes moisture, volatile matter, fixed carbon, ash, and sulfur on a percent by weight basis. An ultimate analysis includes moisture, carbon, hydrogen, sulfur, nitrogen, oxygen, and ash. These analyses may be given on either an as-received or dry basis, or occasionlly on a moisture and ash free basis. Coal is also analyzed for heating value, in Btu/lb, and sometimes for ash chemical analysis and fusion temperatures. Ash-fusion temperatures are important because they are related to slag and ash deposits which can cause operational problems within the boiler or furnace.

b. Oil. Oil is a liquid fossil fuel, normally found far underground (to a depth of five miles or more). Oil and natural gas are as old or older than coal and are the products of marine plants and organisms which were buried and transformed by bacteria and chemical action into complex hydrocarbons. The oil and gas thus formed moved through the sedimentary rock in which it was buried until it was trapped in pockets below solid rock. In general, the deeper in the ground the oil and gas are found, the higher their age and quality. The oil we burn today can come from paraffin base, asphalt base, naphthene base or mixed base crude oil. This oil is refined by fractional distillation at low temperatures and pressure to separate the light ends (straight run No. 1 and No. 2 oil) from the heavier residual oil. The residual oil may be further processed by cracking, catalytic reforming or other processes to produce lighter oils such as cracked No. 2 distillate. Cracked oil contains more olefinic and aromatic hydrocarbons and is more difficult to burn than the paraffinic and naphthenic hydrocarbons found in straight run oil. The "Standard Specification for Fuel Oils" is defined in ASTM D 396. Table 1-2 "Detail Requirements for Fuel Oils" establishes limits for many of the key properties of fuel oil for the various standard grades. Table 1-3 relates API gravity to specific gravity, density, and higher heating value of fuel oils. Knowing the grade and specifications of an oil is only a start toward understanding its handling and combustion characteristics. Because sulfur limits are often imposed on fuel oil, refiners and distributors may blend different oils to meet sulfur limits. For example low sulfur No. 4 oil could be a blend of low sulfur No. 2 and high or medium sulfur No. 6 oil. Problems associated with blended oils may include widely varying viscosity, sludge precipitation, and stratification of the different components. Fairly recent problems have been related to No. 4 oil refined from imported parafin base crude. Paraffin wax from the oil can plate out and clog strainers, even though the oil is fluid. Heating the oil to 90 to 100° F will usually solve this problem. With oil coming from literally every corner of the world, the possible variations are endless and can change with each new tankful. Some of the more common problems are further discussed in chapter 3.

c. Natural Gas. Natural gas was formed by the same processes which produced oil. Compared with coal and oil, natural gas is a simple fuel consisting primarily of methane (CH4, 77% to 90% by volume) and ethane (C2H6, 5% to 15% by volume). Propane and other more complex hydrocarbons are present in small quantities, and inert components such as carbon dioxide and nitrogen may range from 1% to 9% by volume. Typical natural gas has a higher heating value of 1,000 Btu per cubic foot and a specific gravity of 0.6 relative to air. Care is required in handling of natural gas in the vapor state. If leaks in the piping exist, the gas will escape and can be explosive if allowed to collect. Commercial pipeline natural gas has a distinctive "sweet" smell which helps to identify any leakage.

d. Alternate Fuels. Due to rising fuel costs and occasional shortages, it is becoming common to utilize wood, wood waste, municipal waste, agricultural by-products and other wastes to supplement our fossil resources. These alternate fuels may be mixed with more conventional fuels or burned by themselves to reduce the consumption of coal, oil, or gas. This trend will undoubtedly continue and accelerate.

1-5. COMBUSTION

Combustion can be defined as the rapid oxidation of fuel. It is a chemical reaction in which energy is released, in the form of heat and light, when fuel and oxygen combine. Rapid oxidation will not occur without heat to start the reaction. FUEL, OXYGEN, HEAT, and a chemical reaction are necessary for combustion to take place. If any one of these elements is removed, combustion stops. During combustion in a boiler it is important to control the fuel, oxygen, and heat so that the fuel is completely burned and the maximum use is made of its energy. To achieve controlled and efficient combustion three factors must be considered: TIME, TEMPERATURE, and TURBULENCE. Although the oxidation is rapid, several seconds may be required to start and complete the combusion process. Temperature varies during the combustion process with minimum temperatures occurring at the beginning and end. Turbulence is necessary to allow the fuel to be intimately mixed with the oxygen.

a. Chemical Reactions. The following general chemical reactions occur as the combustible carbon (C-molecular weight (MW) = 12), hydrogen (H_2- MW = 2), and sulfur (S-MW = 32) combine with oxygen (O_2-MW = 32) to form cabon dioxide (CO_2-MW = 44), water (H_2O-MW

Table 1-2. Standard Specification for Fuel Oils

Grade of Fuel	Flash Point °C (°F)	Pour Point °C (°F)	Water and Sediment Vol %	Carbon Residue on 10% Bottoms, %	Ash Weight %	Distillation Temperatures, °C (°F) 10% Point	Distillation Temperatures, °C (°F) 90% Point		Saybolt Viscosity, 5 Universal at 38°C (100°F)		Saybolt Viscosity, 5 Fuel at 50°C (122°F)		Specific Gravity 60/60°F (Degree API)	Copper Strip Corrosion	Sulfur %
	Min	Max	Max	Max	Max	Max	Min	Max	Min	Max	Min	Max	Max	Max	Max
No. 1 Distillate	38 (100)	-18 (0)	0.05	0.15	--	215 (420)	--	288 (550)	--	--	--	--	0.8499 (35 min)	No. 3	0.5
No. 2 Distillate	38 (100)	-6 (20)	0.05	0.35	--	--	282 (540)	338 (640)	32.6	37.9	--	--	0.8762 (30 min)	No. 3	0.5
No. 4 Light Residual	55 (130)	-6 (20)	0.50	--	0.10	--	--	--	45	125	--	--	--	--	--
No.5 Light Residual	55 (130)	--	1.00	--	0.10	--	--	--	125	300	--	--	--	--	--
No. 5 Heavy Residual	55 (130)	--	1.00	--	0.10	--	--	--	300	900	23	40	--	--	--
No. 6 Heavy Residual	60 (140)	--	2.00	--	--	--	--	--	900	9000	45	300	--	--	--

Table 1-3. Fuel Oil Characteristics

API Gravity	Specific Gravity	Density lb/gal	Higher Heating Value Btu/lb	Btu/gal
5	1.037	8.633	17,980	155,470
10	1.000	8.328.	18,260	152,280
15	0.966	8.044	18,500	149,030
20	0.934	7.778	18,740	145,880
25	0.904	7.529	18,940	142,820
30	0.876	7.273	19,130	139,660
35	0.850	7.076	19,300	136,720
40	0.825	6.870	19,450	133,760
45	0.802	6.675	19,590	130,910

API Gravity ranges for the fuel oil grades are: No. 1 Oil-46 to 41, No. 2 Oil-39 to 30, No. 4 Oil-28 to 24, No. 5 Oil-22 to 18, No. 6 Oil-17 to 9.

= 18), and sulfur dioxide (SO_2- MW = 64):

$C + O_2 = CO_2$; 12 lb C + 32 lb O_2 = 44 lb CO_2

$2H_2 + O_2 = 2H_2O$; 4 lb H_2 + 32 lb O_2 = 36 lb H_2O

$S + O_2 = SO_2$; 32 lb S = 32 lb O_2 = 64 lb SO_2

These equations may also be written on a weight basis as follows:

1 lb C + 2.66 lb O_2 = 3.66 lb CO_2 + 14,093 Btu

1 lb H2 + 7.94 lb O_2 = 8.94 lb H_2O + 61,100 Btu

1 lb S + 1.00 lb. O_2 = 2.00 lb SO_2 + 3,983 Btu

(1) The following general chemical reactions occur when the simplest hydrocarbon gases, methane (CH_4-MW = 16), ethane (C_2H_6-MW = 30), and propane (C_3H_8 -MW = 44) are oxidized:

$CH_4 + 2O_2 = CO_2 + 2H_2O$; 16 lb CH_4 + 64 lb O_2 = 44 lb CO_2 + 36 lb H_2O

$C_2H_6 + 3.5O_2 = 2CO_2 + 3H_2O$; 30 lb C_2H_6 + 112 lb O_2 = 88 lb Co_2 + 54 lb H_2O

$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$; 44 lb C_3H_8 + 160 lb O_2 = 132 lb CO_2 + 72 lb H_2O

On the basis of weight per pound of fuel, these equations appear as follows

1 lb Ch_4 + 3.99 lb O_2 = 2.74 lb CO_2 + 2.25 lb H_2O + 23,879 Btu

1 lb C_2H_6 + 3.74 lb O_2 = 2.93 lb CO_2 + 1.80 lb H_2O + 22,320 Btu

1 lb C_3H_8 + 3.63 lb O_2 = 2.99 lb CO_2 + 1.64 lb H_2O + 21,661 Btu

(2) In some cases, the oxygen only partially oxidizes to form carbon monoxide (CO) which can then oxidize to form carbon dioxide. A large number of intermediate compounds of carbon, hydrogen and oxygen may also be formed between the start of the combustion process and the final products of combustion listed above. These intermediates are of little practical interest to the boiler operator. The heat of combustion listed above for each reaction is in British Thermal Units (Btu) and is called HIGHER HEATING VALUE (HHV). Some of the heat of combustion (970 Btu per 1 lb H_2O produced) is used to form water and keep it in the vapor state. If this amount of heat is subtracted from the heating values shown above, a quantity called LOWER HEATING VALUE (LHV) is obtained. The common practice in the U.S. is to use higher heating value in combustion calculations, while lower heating value is typically used in Europe. General chemical reactions are a good way to calculate fuel and air requirements. They begin to explain combustion and boiler efficienty.

b. Air Requirements. The air we breathe is 76.7% nigrogen and 23.3% oxygen by weight or 79% nitrogen and 21% oxygen by volume. We use air to obtain oxygen for the combustion process. Each pound of air contains .233 pounds of oxygen. To obtain one pound of oxygen requires 4.29 pounds of air. This is calculated as follows:

$$4.29\ \textit{lb air} \times \frac{0.233\ \textit{lb oxygen}}{1.0\ \textit{lb air}} = 1.0\ \text{lb}\textit{oxygen}$$

Each 4.29 pounds of air contains 1 pound of oxygen and 3.29 pounds of nitrogen. The nitrogen is not chemically active in the combustion process; however, it lowers the flame temperature by absorbing heat and carrying it away from the boiler in the flue gas. The combustion equation given in the previous paragraph can be used to calculate the exact quantity of oxygen, and hence air, required to completely react with a given amount of fuel. This quantity of air is called THEORETICAL AIR. Unfortunately, the use and control of the combustion process in a boiler is not perfect and an additional quantity of air called EXCESS AIR is needed to achieve complete combustion.

c. Excess Air Example. Combustion of one pound of No. 2 oil with an analysis of 87 percent carbon, 12 percent hydrogen, 0.5 percent sulfur, and 0.5 percent nitrogen requires theoretical air as determined below:

.87 lb C x 2.66 lb O_2/ lb C	= 2.31 lb O_2
.12 lb H_2 x 7.94 lb O_2/ lb H_2	= 0.95 lb O_2
.005 lb S x 1.00 lb O_2/ lb S	= 0.01 lb O_2
Theoretical Oxygen	= 3.27 lb O_2

In a moderately well-controlled burner approximately 20 percent excess air is typically required to ensure complete combustion.

Theoretical air = 3.27 lb O_2 x 4.29 lb air/ lb O_2 = 14.0 lb air. The total combustion air per pound of fuel required thus becomes:

14.0 lb air + (14.0 lb air x .20) = 16.8 lb air.

If the combustion process is not well controlled, 50 percent excess air may enter the furnace through the burner. The total combusion air per pound of fuel then becomes.:

14.0 lb. air +1 (14.0 lb air x .50) = 21.0 lb. air.

Figure 1.4 illustrates these relationships and the combustion products.

d. Higher Heating Values. Higher heating values of fuels are best determined by calorimeter test. If the ultimate analysis of an oil or coal is known, Dulong's formula may be used to determine HHV of a liquid or solid fuel. Dulong's formula is given below and may be considered accurate to within 2 or 3 percent.

$$HHV = 14{,}544C + 62{,}028\,(H_2\text{-}O_2/8) + 4050\,S$$

The carbon, hydrogen, oxygen, and sulfur come from the ultimate analysis and are expressed in percent by weight. The coefficients represent the approximate heating values of the constituents in Btu/lb and the result obtained is also in Btu/lb. The $O_2/8$ is a correction applied to the hydrogen in the fuel to account for the fact that some of the hydrogen is already combined with oxygen to form water. The Dulong formula is not suitable for gaseous fuels because the heat of formation of constituents like methane and ethane is not considered. For gaseous fuels the HHV

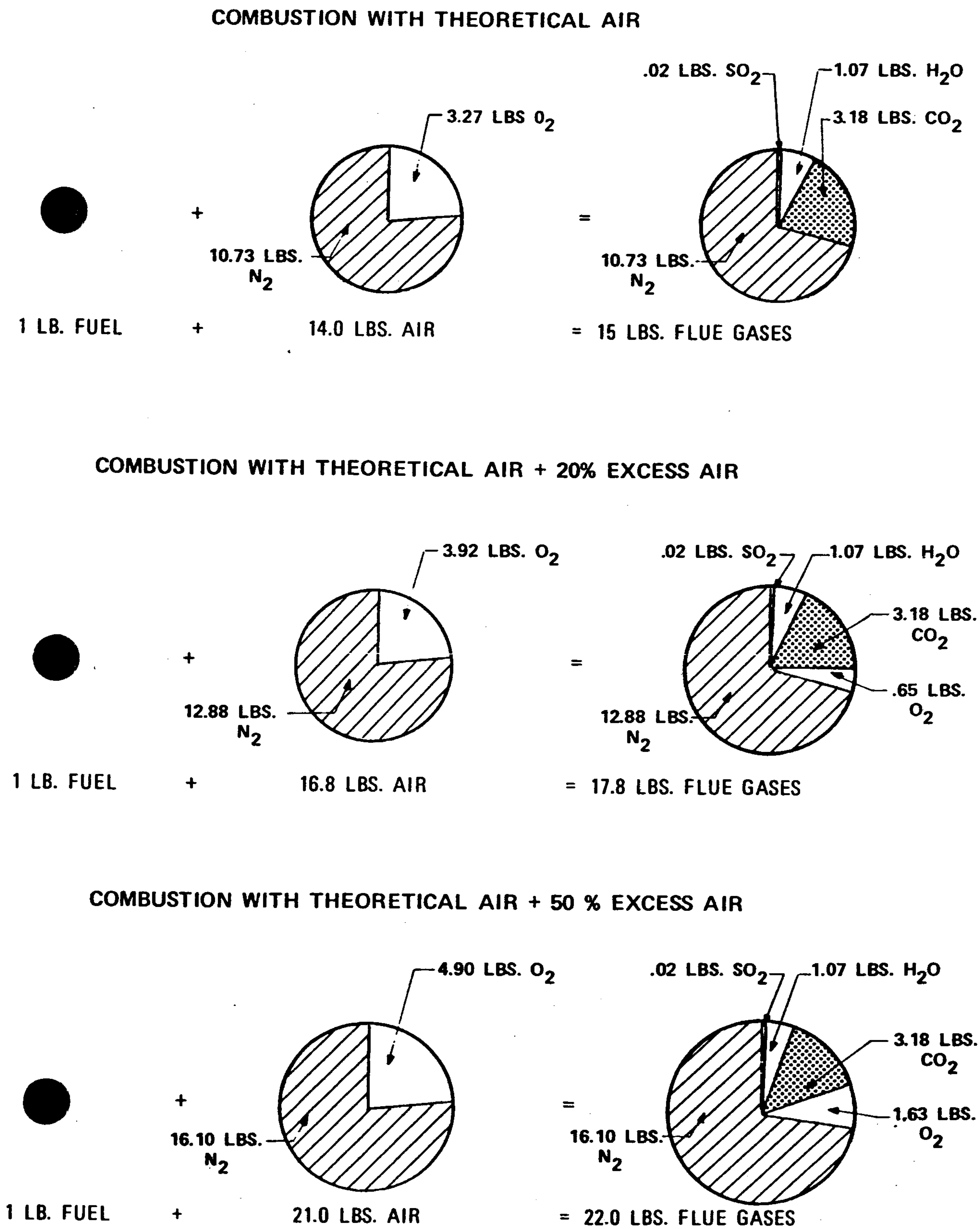

FIGURE 1–4. COMBUSTION OF OIL

may be determined by taking a weight average of heating values for each gaseous constituent. Care must be taken in evaluating the heating value of fuel oils. A No. 6 fuel oil may have a lower heating value than a No. 2 oil when measured on a Btu/lb basis, but since it is more dense, the No. 6 oil could well have more Btu/gallon. This is significant since oil is normally purchased by the gallon rather than by the pound. Table 1-3 provides a comparison of the API gravity, specific gravity, Btu/lb, and Btu/gallon for ranges of fuel oils.

1-6. COMBUSTION OF COAL

The fundamentals of coal combustion are illustrated in figure 1-5 which represents hand-fired grate burning. A uniform fuel bed eight inches thick is maintained on the grate. About 50 percent of the air required for combustion enters from below the grate and passes through a layer of ash. The oxygen in this air is consumed while passing through the first few inches of burning fixed carbon. This is called the oxidizing zone. Heat from burning the fixed carbon rises and drives moisture and volatile matter from the raw coal in the oxygen-deficient reducing zone at the top of the bed. The remaining fixed carbon from the top of the bed later burns in the bottom of the bed as additional raw coal is added to the top. Volatile matter in the vapor form and carbon monoxide just above the bed must be fully mixed with overfire air to complete the combustion process. At low firing rates it is important to minimize the amount of overfire air to prevent cooling of the volatile matter resulting in incomplete combustion and soot formation. At intermediate and high firing rates the ability to fully mix volatile matter, carbon monoxide, and overfire air determines the practrical excess air levels that can be maintained and completeness of combustion. The rate of combustion is controlled by the underfire combustion air. The efficienty of combustion is determined by the effective turbulent use of overfire combustion air. Stokers may use fans, ducts, air compartments, modulating air dampers, cinder reinjection systems, coal feeders, and moving or vibrating grates to provide better control of the firing rate and efficiency of the coal combustion. In some stokers, a portion of the coal may be burned in suspension before it falls onto the grate. In underfeed stokers, the raw coal is delivered from below the burning coal. Pulverized coal firing systems utilize pulverizers to grind coal to a fine dust. This dust is conveyed by primary combustion air to a burner which serves to ignite the coal and mix additional secondary combustion air with the stream of primary air and coal. The pulverized coal is completely burned in suspension. The principles of coal combustion remain the same for any of these variations. Moisture and volatile matter must be driven off before the fixed carbon can be burned and combustion air must be effectively mixed with the volatile vapors to efficiently complete combustion.

1-7. COMBUSTION OF OIL

The combustion of fuel oil occurs after the liquid oil is varporized. The time required for combustion is initially dependent upon the ability of the burner to atomize the oil into fine droplets and provide heat to vaporize the oil. The vapor is then ignited and turbulently mixed with combustion air to stabilize ignition in an ignition zone. The heavy hydrocarbons crack, as described in paragraph 1-9, to give the oil flame its yellow color. The burner must supply additional air to mix with the remaining fuel with adequate time, temperature and turbulence for complete combustion. Careful control and adjustment of the flow of air, oil, and atomizing steam/air are needed to achieve maximum efficiency at all boiler loads.

1-8. COMBUSTION OF NATURAL GAS

Natural gas consists mainly of the simple hydrocarbons methane and ethane and is the easiest fuel to burn, although it can also be the most dangerous. Given the proper time, temperature, turbulence and excess air, gas can sometimes burn without a visible flame or with a blue flame. If some of the hydrocarbons crack as described in paragraph 1-9, a yellow flame will be present. One danger of natural gas combustion is that carbon monoxide, which is poisonous in very low concentrations, may be produced if there is insufficient air or insufficient mixing. For safety and efficiency reasons, incomplete combustion should be avoided by proper control of fuel and air. There is a range of air-gas mixtures which burn violently and explosively. This range varies between 8 and 13 percent gas by volume, depending upon the particular hydrocarbon. Leaner mixtures, 0 to 7 percent, do not explode or burn, while richer mixtures typical of the ignition zone in the combustion process, burn more slowly and do not explode. If a rich concentration of vapor exists, however, it vill gradually diffuse into the air and will at some time be within the explosive range. If this mixture comes in contact with a spark or open flame an explosion can occur. In order to prevent buildup of such concentrations, safety shut-off valves are installed on natural gas and oil combustion systems and are very important. Purging of the boiler setting both before and after combustion of any fuel is also extremely important in the prevention of explosions.

1-9. SOOT AND SMOKE

Understanding the causes of soot and smoke is the first step in their prevention.

a. Soot. Soot is unburned carbon from the fuel. The

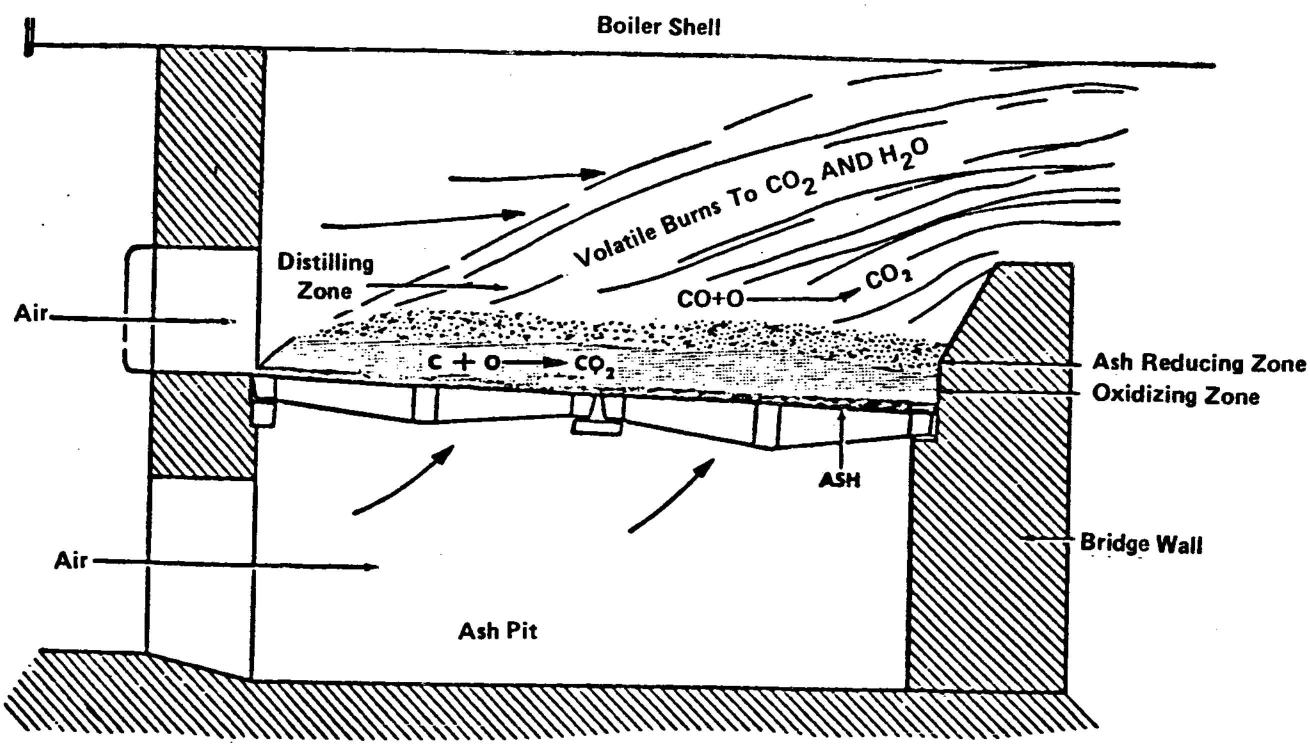

FIGURE 1-5. COMBUSTION OF COAL

finely divided soot particles give flue gases a black color when present. In the refining oil, heavy hydrocarbons are cracked into simpler hydrocarbons, carbon, and hydrogen. This cracking (thermal decomposition) process is also one of the reactions which occur when a fuel is burned. For example, if methane gas is slowly heated and mixed with air, the gas burns with no visible flame or a blue flame. The methane is oxidized without cracking and several intermediate carbon/hydrogen/oxygen compounds are formed. However, if the methane is heated quickly, the gas is cracked into hydrogen and carbon. The carbon particles glow when burnt, giving off a yellow color. If this yellow flame comes in contact with a boiler tube, the carbon in the flame can be cooled and deposited on the tube as soot. If a flame containing elemental carbon is not given enough time and proper temperature for combustion, soot will form as the carbon cools. For example, when a boiler is fired beyond its rated capacity, it is required to burn more fuel in the same furnace. When this happens, the time available for combustion is shortened, and may become so short that complete combustion is not possible. Another potential time for soot to form is during the start-up of a cold boiler or while operating at low-fire. Under these conditions, enough heat may be transferred from the flame to cool it below its ignition temperature and cause the formation of soot.

b. Smoke. Smoke seen in boiler flue gas results from the presence of soot and ash from the combustion process. It is difficult to make natural gas fire smoke, but oil and coal, if not properly controlled, will smoke readily due to the more rapid cracking of their complex hydrocarbons. While the heat loss from unburned carbon may not be significant (tenths of a percent of efficiency), smoke formation indicates a waste of fuel and a possible soot buildup in the furnace and convection passes. Such buildups can result in large efficiency losses associated with reduced heat transfer and higher boiler exit gas temperatures. Smoke of colors other than black is less noticeable but can be just as wasteful. Blue smoke from an oil-fired boiler indicates that a portion of the oil is not being cracked while white smoke generally indicates high excess air levels. In either case, a major burner problem is indicated. It is common practice when adjusting the combustion process to start with high excess air and white smoke. At some lower range of excess airs no smoke will be visible and finally, at still lower excess air levels, black smoke will occur. Coal-fired often generate white smoke related to the ash in the coal.

c. Stack Opacity. Operating with a minimum practical level of smoke as measured by stack opacity indicates a generally well run boiler plant. Stack opacity is measured on a 0 percent (clear) to 100 percent (completely opaque) scale. A practical level of smoke would be less than local opacity limits (typically 10 to 20 percent) and based upon obtaining optimum boiler efficiency. A slight decrease in opacity may not be acceptable if it must be obtained with a large increase in excess air. When burning coal, the amount of carbon in the stoker and collection hoppers should be considered when reviewing excess air and opacity levels.

1-10. FLUE GAS ANALYSIS AND TEMPERATURE

The performance of a burner and boiler can largely be determined by analysis and temperature of the flue gas. The flue gas temperature at the boiler, economizer, or air heater outlet provides information on boiler cleanliness, firing rate, and efficiency. Flue gas analysis establishes the amount of oxygen, carbon dioxide, and carbon monoxide in the flue gas. This analysis is generally on a dry basis by volume since the water vapor is condensed before analysis. Given the type of fuel being burned and the oxygen or carbon dioxide level, tables 1-4 through 1-8 can be used to determine the percent of excess air in the flue gas for natural gas, No. 2 oil, No. 6 oil, and coal. Gas absorption analyzers like the Orsat and "FYRITE" CO_2 bottle are occasionally used to monitor system efficiency. These two analyzers are adequate for monitoring steady boiler loads if care is used in obtaining samples and maintaining the analyzer. Continuous analyzers are also available using either a fuel cell or zirconium oxide element to monitor oxygen levels. The technology of these analyzers is advancing rapidly and many of the current models are accurate, easy to maintain, and will provide a continuous record of the flue gas analysis. By using a continuous monitor an operator can immediately observe the results of firing rate changes and can see how the oxygen level changes at different points in the flue. Monitoring different points in a flue can help to determine if the boiler setting is leaking. Figure 1-6 illustrates an efficiency monitor which includes an oxygen analyzer, carbon monoxide analyzer, smoke tester, thermocouple, and digital readouts for the various measurements. Combustibles analyzers are also available and are particularly valuable for natural gas fired boilers. Smoke density or opacity monitors are commonly used for tuning and monitoring boiler operation.

1-11. COMBUSTION EFFICIENCY

Boiler combustion efficiency can be determined if proper information is available on fuel analysis, flue gas analysis, combustion air temperature, and stack temperature. The loss of heat in the flue gas, on a percentage basis, is subtracted from 100 percent to provide the percentage combustion efficiency. The heat lost with the flue gas is

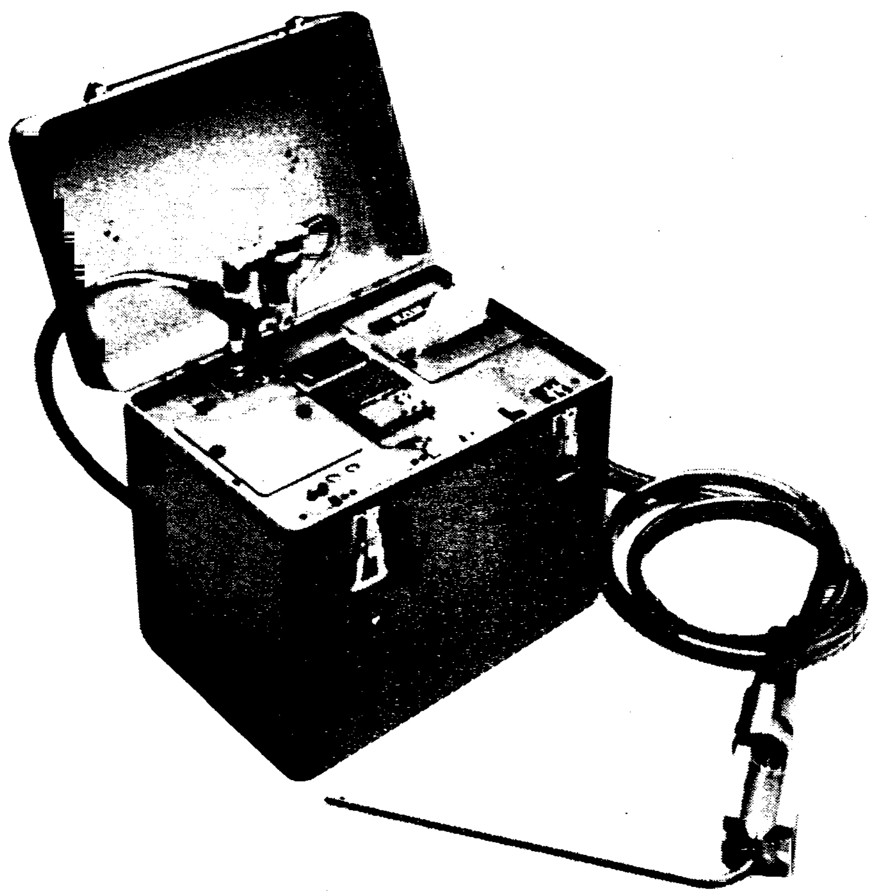

FIGURE 1-6. COMBUSTION EFFICIENCY MONITOR

determined by its temperature and chemical analysis. The amounts of excess air and water vapor are most important in determining their loss. Water is contained in the flue gas in its vapor state. Each pound of water vapor requires 970 Btu of the energy supplied to the boiler to maintain it in its vapor state. In addition to this 970 Btu/lb, water vapor also contains 80% more energy per pound than the other flue gas constituents. The effect of this water vapor on boiler efficiency can be illustrated by comparing a natural gas fired boiler to one fired by oil. For identical levels of excess air, combustion air temperature and stack temperature, the natural gas fired boiler will have a lower combustion efficiency than the oil fired boiler. This happens because natural gas contains more hydrogen than oil and thus has more water in the flue gas. Using table 1-4 and 1-6, at 15% excess air, 70° F combustion air temperature, and 530° F stack temperature, the combustion efficiency of a natural gas fired boiler is 78.9° as compared with 83.4° for a No. 6 oil-fired boiler. Tables 1-4 through 1-8 are Combustion Efficiency Tables for natural gas, No. 2 oil, No. 6 oil, coal with 3.5° moisture, and coal with 9.0° moisture respectively. The combustion efficiency for No. 4 oil may be considered the average of the combustion efficiencies for No. 2 oil and No. 6 oil. Expanded versions of the tables presented here may be found in the Boiler Efficiency Institute book entitled "Boiler Efficiency Improvement."

1-12. BOILER EFFICIENCY

Boiler efficiency is simply defined as the amount of energy in the steam or hot water leaving the boiler (E out, Btu/lb x lb/hr = Btu/hr) minus the energy in the feedwater (E fw., Btu/lb x lb hr) divided by the amount of energy in the fuel used (E fuel, Btu/lb x lb/hr).

$$\text{Boiler Efficiency} = \frac{(\text{E out - E fw.})}{\text{E fuel}}$$

Boiler efficiency must always be less than combustion efficiency. Typical boiler efficiencies range from 75 to 85 percent. The main boiiler loss is the heat lost in the flue gas as discussed in the previous paragraph. Other energy losses are associated with heat radiated from the boiler casing, heat carried away by the blowdown water, and heat lost because of incomplete combustion. To achieve maximum boiler efficiency the operator must:

— Minimize excess air to reduce stack losses.
— Clean the gas side and water side of the boiler tubes to ensure maximum absorption of heat and reduced stack temperatures.
— Minimize blowdown to reduce blowdown losses.
— Perform maintenance on burners and controls to minimize unburned fuel.

A more detailed discussion of boiler efficiency is provided in chapter 3.

1-13. CENTRAL BOILER PLANT EFFICIENCY

The amount of energy in the steam or hot water leaving the plant (E out of plant, Btu/lb x lb/hr) minus the amount of energy in the condensate or hot water return (E return, Btu/lb x lb/hr), divided by the amount of energy in the fuel (E fuel, Btu/lb x lb/hr) used to produce that steam or hot water is the Central Boiler Plant efficiency.

$$\textit{Plant Efficiency} = \frac{(\textit{E out of plant} - \textit{E return})}{\textit{E fuel}}$$

Boiler selection, deaerator control, steam trap maintenance, use of steam driven auxiliaries, and plant building energy conservation are all important contributing elements to boiler plant efficiency. Energy losses and use should be controlled to keep plant efficiency as close as possible to boiler efficiency. The use of steam driven auxiliaries reduces the amount of energy sent out of the central plant and steam losses can result if the exhaust steam cannot be used in the deaerator or building heating system. Distribution system losses should also be monitored and reported from the Central Boiler Plant. While strictly speaking they are not a part of central plant efficiency, distribution system losses greatly affect the efficiency of the system. Any makeup water required to replace distribution losses must be heated to the feedwater temperature. This requires additional steam to be generated by the boilers, thus using additional fuel and lowering plant efficiency. More information is provided in chapter 3.

Table 1-4. Combustion Efficiency for Natural Gas

% Excess Air	% O_2	% CO_2	Percent Combustion Efficiency — Flue Gas Temperature Minus Combustion Air Temperature, Deg F: 180	220	260	300	340	380	420	460	500	540	580	620
0.0	0.0	11.8	86.1	85.3	84.5	83.6	82.8	81.9	81.0	80.1	79.3	78.4	77.5	76.6
4.5	1.0	11.2	86.0	85.1	84.2	83.4	82.5	81.6	80.7	79.8	78.9	77.9	77.0	76.1
9.5	2.0	10.7	85.8	84.9	84.0	83.1	82.2	81.2	80.3	79.4	78.4	77.5	76.5	75.5
12.1	2.5	10.4	85.7	84.8	83.9	83.0	82.0	81.1	80.1	79.1	78.2	77.2	76.2	75.2
15.0	3.0	10.1	85.7	84.7	83.8	82.8	81.8	80.9	79.9	78.9	77.9	76.9	75.9	74.9
18.0	3.5	9.8	85.6	84.6	83.6	82.6	81.7	80.7	79.7	78.7	77.6	76.6	75.6	74.6
21.1	4.0	9.6	85.5	84.5	83.5	82.5	81.5	80.5	79.4	78.4	77.4	76.3	75.3	74.2
24.5	4.5	9.3	85.4	84.3	83.3	82.3	81.3	80.2	79.2	78.1	77.1	76.0	74.9	73.8
28.1	5.0	9.0	85.2	84.2	83.2	82.1	81.1	80.0	78.9	77.8	76.7	75.6	74.5	73.4
31.9	5.5	8.7	85.1	84.1	83.0	81.9	80.8	79.7	78.6	77.5	76.4	75.3	74.1	73.0
35.9	6.0	8.4	85.0	83.9	82.8	81.7	80.6	79.5	78.3	77.2	76.0	74.9	73.7	72.5
40.3	6.5	8.2	84.9	83.7	82.6	81.5	80.3	79.2	78.0	76.8	75.6	74.5	73.3	72.0
44.9	7.0	7.9	84.7	83.5	82.4	81.2	80.0	78.8	77.6	76.4	75.2	74.0	72.8	71.5
49.9	7.5	7.6	84.5	83.4	82.2	80.9	79.7	78.5	77.3	76.0	74.8	73.5	72.2	71.0
55.3	8.0	7.3	84.4	83.1	81.9	80.7	79.4	78.1	76.9	75.6	74.3	73.0	71.7	70.4
67.3	9.0	6.7	84.0	82.7	81.4	80.0	78.7	77.3	76.0	74.6	73.2	71.8	70.4	69.0
81.6	10.0	6.2	83.5	82.1	80.7	79.3	77.8	76.4	74.9	73.4	71.9	70.4	68.9	67.4
98.7	11.0	5.6	83.0	81.5	79.9	78.3	76.8	75.2	73.6	72.0	70.4	68.8	67.1	65.5
119.7	12.0	5.1	82.3	80.6	78.9	77.2	75.5	73.8	72.0	70.3	68.5	66.7	64.9	63.1
145.8	13.0	4.5	81.5	79.6	77.7	75.8	73.9	72.0	70.1	68.1	66.2	64.2	62.2	60.2
179.5	14.0	3.9	80.4	78.3	76.2	74.0	71.9	69.7	67.5	65.3	63.1	60.9	58.7	56.4
224.3	15.0	3.4	79.0	76.6	74.1	71.7	69.2	66.7	64.2	61.7	59.1	56.5	54.0	51.4

This table is based on the following fuel analysis (% by weight): carbon-70.8%, hydrogen-23.4%, nitrogen-3.8%, oxygen-1.2%, carbon dioxide-.8%. The higher heating value is 21,700 Btu/lb.

Table 1-5. Combustion Efficiency for Number 2 Oil

% Excess Air	% O_2	% CO_2	Percent Combustion Efficiency — Flue Gas Temperature Minus Combustion Air Temperature, Deg F: 180	220	260	300	340	380	420	460	500	540	580	620
0.0	0.0	15.6	90.4	89.6	88.8	88.0	87.1	86.3	85.5	84.7	83.8	83.0	82.1	81.3
4.7	1.0	14.9	90.2	89.4	88.6	87.7	86.9	86.0	85.2	84.3	83.4	82.5	81.6	80.7
9.9	2.0	14.1	90.1	89.2	88.3	87.4	86.6	85.7	84.8	83.9	82.9	82.0	81.1	80.2
12.6	2.5	13.8	90.0	89.1	88.2	87.3	86.4	85.5	84.6	83.6	82.7	81.8	80.8	79.9
15.6	3.0	13.4	89.9	89.0	88.1	87.1	86.2	85.3	84.3	83.4	82.4	81.5	80.5	79.5
18.7	3.5	13.0	89.8	88.9	87.9	87.0	86.0	85.1	84.1	83.1	82.2	81.2	80.2	79.2
22.0	4.0	12.6	89.7	88.7	87.8	86.8	85.8	84.9	83.9	82.9	81.9	80.9	79.8	78.8
25.5	4.5	12.3	89.6	88.6	87.6	86.6	85.6	84.6	83.6	82.6	81.6	80.5	79.5	78.4
29.2	5.0	11.9	89.5	88.5	87.4	86.4	85.4	84.4	83.3	82.3	81.2	80.2	79.1	78.0
33.2	5.5	11.5	89.3	88.3	87.3	86.2	85.2	84.1	83.0	82.0	80.9	79.8	78.7	77.6
37.4	6.0	11.2	89.2	88.1	87.1	86.0	84.9	83.8	82.7	81.6	80.5	79.4	78.3	77.1
41.9	6.5	10.8	89.1	88.0	86.9	85.8	84.6	83.5	82.4	81.3	80.1	79.0	77.8	76.6
46.8	7.0	10.4	88.9	87.8	86.6	85.5	84.4	83.2	82.0	80.9	79.7	78.5	77.3	76.1
52.0	7.5	10.0	88.7	87.6	86.4	85.2	84.1	82.9	81.7	80.4	79.2	78.0	76.7	75.5
57.6	8.0	9.7	88.6	87.4	86.2	84.9	83.7	82.5	81.2	80.0	78.7	77.5	76.2	74.9
70.2	9.0	8.9	88.2	86.9	85.6	84.3	83.0	81.6	80.3	79.0	77.6	76.2	74.9	73.5
85.0	10.0	8.2	87.7	86.3	84.9	83.5	82.1	80.6	79.2	77.8	76.3	74.8	73.3	71.8
102.9	11.0	7.4	87.1	85.6	84.1	82.6	81.0	79.5	77.9	76.3	74.7	73.1	71.5	69.9
124.7	12.0	6.7	86.5	84.8	83.1	81.4	79.7	78.0	76.3	74.5	72.8	71.0	69.2	67.4
152.0	13.0	6.0	85.6	83.7	81.9	80.0	78.1	76.2	74.3	72.3	70.4	68.4	66.4	64.4
187.0	14.0	5.2	84.5	82.4	80.3	78.2	76.0	73.8	71.7	69.5	67.3	65.0	62.8	60.5
233.7	15.0	4.5	83.0	80.6	78.2	75.7	73.2	70.7	68.2	65.7	63.1	60.6	58.0	55.4

This table is based on the following fuel anaysis (% by weight): carbon-86.7%, hydrogen-12.4%, nitrogen-.1%, sulfur-.8%. The higher heating value is 19,500 Btu/lb.

Table 1-6. Combustion Efficiency for Number 6 Oil

% Excess Air	% O_2	% CO_2	Percent Combustion Efficiency — Flue Gas Temperature Minus Combustion Air Temperature, Deg F											
			180	220	260	300	340	380	420	460	500	540	580	620
0.0	0.0	16.5	91.2	90.4	89.6	88.8	87.9	87.1	86.3	85.4	84.6	83.7	82.9	82.0
4.7	1.0	15.7	91.0	90.2	89.4	88.5	87.7	86.8	85.9	85.1	84.2	83.3	82.4	81.5
10.0	2.0	14.9	90.9	90.0	89.1	88.2	87.3	86.4	85.5	84.6	83.7	82.8	81.8	80.9
12.8	2.5	14.5	90.8	89.9	89.0	88.1	87.2	86.3	85.3	84.4	83.4	82.5	81.5	80.6
15.8	3.0	14.1	90.7	89.8	88.9	87.9	87.0	86.1	85.1	84.1	83.2	82.2	81.2	80.2
18.9	3.5	13.8	90.6	89.7	88.7	87.8	86.8	85.8	84.9	83.9	82.9	81.9	80.9	79.9
22.3	4.0	13.4	90.5	89.5	88.6	87.6	86.6	85.6	84.6	83.6	82.6	81.6	80.5	79.5
25.8	4.5	13.0	90.4	89.4	88.4	87.4	86.4	85.4	84.3	83.3	82.3	81.2	80.2	79.1
29.6	5.0	12.6	90.3	89.2	88.2	87.2	86.2	85.1	84.1	83.0	81.9	80.9	79.8	78.7
33.6	5.5	12.2	90.1	89.1	88.0	87.0	85.9	84.8	83.8	82.7	81.6	80.5	79.4	78.2
37.9	6.0	11.8	90.0	88.9	87.8	86.8	85.7	84.6	83.4	82.3	81.2	80.0	78.9	77.7
42.4	6.5	11.4	89.8	88.7	87.6	86.5	85.4	84.2	83.1	81.9	80.8	79.6	78.4	77.2
47.3	7.0	11.0	89.7	88.6	87.4	86.3	85.1	83.9	82.7	81.5	80.3	79.1	77.9	76.7
52.6	7.5	10.6	89.5	88.3	87.2	86.0	84.8	83.6	82.3	81.1	79.9	78.6	77.4	76.1
58.2	8.0	10.2	89.3	88.1	86.9	85.7	84.4	83.2	81.9	80.6	79.4	78.1	76.8	75.5
71.0	9.0	9.4	88.9	87.6	86.3	85.0	83.7	82.3	81.0	79.6	78.2	76.8	75.4	74.0
86.0	10.0	8.6	88.5	87.0	85.6	84.2	82.7	81.3	79.8	78.3	76.9	75.4	73.9	72.3
104.1	11.0	7.9	87.9	86.3	84.8	83.2	81.7	80.1	78.5	76.9	75.2	73.6	72.0	70.3
126.1	12.0	7.1	87.2	85.5	83.8	82.1	80.3	78.6	76.8	75.0	73.3	71.5	69.6	67.8
153.7	13.0	6.3	86.3	84.4	82.5	80.6	78.6	76.7	74.7	72.8	70.8	68.8	66.8	64.7
189.1	14.0	5.5	85.2	83.0	80.9	78.7	76.5	74.3	72.1	69.8	67.6	65.3	63.0	60.7
236.4	15.0	4.7	83.7	81.2	78.7	76.2	73.6	71.1	68.5	65.9	63.3	60.7	58.1	55.4

This table is based on the following fuel analysis (% by weight): carbon-88.4%, hydrogen-10.0%, nitrogen-0.9%, sulfur-.7%. The higher heating value is 18,300 Btu/lb.

Table 1-7. Combustion Efficiency for Coal, 3.5% Moisture, Bituminous

% Excess Air	% O_2	% CO_2	Percent Combustion Efficiency Flue Gas Temperature Minus Combustion Air Temperature, Deg F											
			180	220	260	300	340	380	420	460	500	540	580	620
0.0	0.0	18.4	92.0	91.2	90.3	89.5	88.6	87.7	86.8	85.9	85.0	84.1	83.1	82.2
4.8	1.0	17.6	91.9	91.0	90.1	89.2	88.3	87.3	86.4	85.5	84.5	83.6	82.6	81.6
10.2	2.0	16.7	91.7	90.8	89.8	88.9	87.9	86.9	86.0	85.0	84.0	83.0	82.0	81.0
16.2	3.0	15.8	91.5	90.5	89.5	88.5	87.5	86.5	85.5	84.5	83.4	82.4	81.3	80.3
22.8	4.0	14.9	91.3	90.2	89.2	88.2	87.1	86.0	85.0	83.9	82.8	81.7	80.6	79.5
26.4	4.5	14.5	91.1	90.1	89.0	87.9	86.9	85.8	84.7	83.6	82.4	81.3	80.2	79.0
30.3	5.0	14.0	91.0	89.9	88.8	87.7	86.6	85.5	84.4	83.2	82.1	80.9	79.7	78.6
34.4	5.5	13.6	90.9	89.8	88.6	87.5	86.3	85.2	84.0	82.9	81.7	80.5	79.3	78.1
38.8	6.0	13.2	90.7	89.6	88.4	87.2	86.1	84.9	83.7	82.5	81.3	80.0	78.8	77.6
43.5	6.5	12.7	90.6	89.4	88.2	87.0	85.8	84.5	83.3	82.1	80.8	79.5	78.3	77.0
48.5	7.0	12.3	90.4	89.2	87.9	86.7	85.4	84.2	82.9	81.6	80.3	79.0	77.7	76.4
53.9	7.5	11.9	90.2	88.9	87.7	86.4	85.1	83.8	82.5	81.1	79.8	78.5	77.1	75.7
59.7	8.0	11.4	90.0	88.7	87.4	86.1	84.7	83.4	82.0	80.6	79.2	77.9	76.5	75.0
65.9	8.5	11.0	89.8	88.4	87.1	85.7	84.3	82.9	81.5	80.1	78.6	77.2	75.8	74.3
72.7	9.0	10.5	89.6	88.2	86.7	85.3	83.9	82.4	81.0	79.5	78.0	76.5	75.0	73.5
80.1	9.5	10.1	89.3	87.9	86.4	84.9	83.4	81.9	80.4	78.8	77.3	75.7	74.2	72.6
88.1	10.0	9.7	89.0	87.5	86.0	84.4	82.9	81.3	79.7	78.1	76.5	74.9	73.3	71.6
106.6	11.0	8.8	88.4	86.8	85.1	83.4	81.7	80.0	78.2	76.5	74.7	73.0	71.2	69.4
129.2	12.0	7.9	87.7	85.8	84.0	82.1	80.2	78.3	76.4	74.5	72.6	70.6	68.7	66.7
157.5	13.0	7.0	86.7	84.6	82.6	80.5	78.4	76.3	74.2	72.0	69.9	67.7	65.5	63.3
193.8	14.0	6.1	85.5	83.1	80.8	78.4	76.0	73.6	71.2	68.8	66.4	63.9	61.4	58.9
242.2	15.0	5.3	83.8	81.1	78.4	75.7	72.9	70.1	67.4	64.5	61.7	58.9	56.0	53.1

This table is based on the following fuel analysis (% by weight): ash-5.0%, sulfur-0.92%, hydrogen-5.12%, carbon-77.13%, moisture-3.50%, nitrogen-1.49%, oxygen-6.84%. The proximate analysis is VM-36.14%, FC-55.36%, M-3.5%, ash-5.0%. The higher heating value of this Class II Group 3 bituminous coal is 13,750 Btu/lb.

Table 1-8. Combustion Efficiency for Coal, 9.0% Moisture, Bituminous

% Excess Air	% O_2	% CO_2	Percent Combustion Efficiency: Flue Gas Temperature Minus Combustion Air Temperature, Deg F											
			180	220	260	300	340	380	420	460	500	540	580	620
0.0	0.0	18.4	91.0	90.1	89.2	88.3	87.4	86.5	85.6	84.7	83.7	82.8	81.8	80.9
4.8	1.0	17.6	90.8	89.9	89.0	88.1	87.1	86.2	85.2	84.2	83.2	82.3	81.3	80.3
10.2	2.0	16.7	90.7	89.7	88.7	87.7	86.8	85.8	84.8	83.7	82.7	81.7	80.6	79.6
16.2	3.0	15.8	90.5	89.4	88.4	87.4	86.4	85.3	84.3	83.2	82.1	81.1	80.0	78.9
22.8	4.0	14.9	90.2	89.2	88.1	87.0	85.9	84.8	83.7	82.6	81.5	80.3	79.2	78.1
26.4	4.5	14.5	90.1	89.0	87.9	86.8	85.7	84.6	83.4	82.3	81.1	80.0	78.8	77.6
30.3	5.0	14.0	90.0	88.8	87.7	86.6	85.4	84.3	83.1	81.9	80.7	79.6	78.3	77.1
34.4	5.5	13.6	89.8	88.7	87.5	86.3	85.2	84.0	82.8	81.6	80.3	79.1	77.9	76.6
38.8	6.0	13.2	89.7	88.5	87.3	86.1	84.9	83.6	82.4	81.2	79.9	78.7	77.4	76.1
43.5	6.5	12.7	89.5	88.3	87.1	85.8	84.6	83.3	82.0	80.7	79.5	78.2	76.8	75.5
48.5	7.0	12.3	89.3	88.1	86.8	85.5	84.2	82.9	81.6	80.3	79.0	77.6	76.3	74.9
53.9	7.5	11.9	89.1	87.8	86.5	85.2	83.9	82.5	81.2	79.8	78.4	77.1	75.7	74.3
59.7	8.0	11.4	88.9	87.6	86.2	84.9	83.5	82.1	80.7	79.3	77.9	76.4	75.0	73.5
65.9	8.5	11.0	88.7	87.3	85.9	84.5	83.1	81.6	80.2	78.7	77.3	75.8	74.3	72.8
72.7	9.0	10.5	88.5	87.0	85.6	84.1	82.6	81.1	79.6	78.1	76.6	75.1	73.5	71.9
80.1	9.5	10.1	88.2	86.7	85.2	83.7	82.1	80.6	79.0	77.5	75.9	74.3	72.7	71.0
88.1	10.0	9.7	88.0	86.4	84.8	83.2	81.6	80.0	78.4	76.7	75.1	73.4	71.7	70.1
106.6	11.0	8.8	87.3	85.6	83.9	82.1	80.4	78.6	76.9	75.1	73.3	71.5	69.6	67.8
129.2	12.0	7.9	86.5	84.6	82.7	80.8	78.9	77.0	75.0	73.0	71.1	69.1	67.0	65.0
157.5	13.0	7.0	85.6	83.4	81.3	79.2	77.0	74.9	72.7	70.5	68.3	66.1	63.8	61.6
193.8	14.0	6.1	84.3	81.9	79.5	77.1	74.6	72.2	69.7	67.2	64.7	62.2	59.7	57.1
242.2	15.0	5.3	82.6	79.8	77.1	74.3	71.5	68.6	65.8	62.9	60.0	57.1	54.1	51.2

This table is based on the following fuel analysis (% by weight): ash-8.0%, sulfur-1.91%, hydrogen-4.48%, carbon-67.40%, moisture-9.00%, nitrogen-1.31%, oxygen-7.90%. The proximate analysis is VM-33.86%, FC-49.14%, M-9.0%, Ash-8.0%. The higher heating value of this Class II Group 4 bituminous coal is 12,050 Btu/lb.